Intoduction to Complex Systems

A new course for students in the Physical Sciences, Computer Sciences, and Mathematics, by Professor Sergey Buldyrev.

The definition of a complex system is somewhat loose. Can, for example, a mechanical clock which consists of many interacting parts be regarded as a complex system? From our point of view, it cannot. Good examples of complex systems include human societies, market economies, ecosystems, living cells, genomes, the world climate, and the Internet.

One of the greatest scientific advances in the last three decades was the development of a new interdisciplinary field of complex systems. The main idea of this emerging branch of science is that some aspects of complex systems can be modeled by a large number of interacting agents not unlike the way statistical physics describes the behavior of magnets and liquids consisting of a large number of interacting atoms and molecules.

One of the main features of complex systems is that interacting agents (for example, ants in an anthill who lack centralized control and whose interactions are short-ranged) exhibit large scale coordinated behavior (build an anthill). This behavior is often manifested by complex patterns and shapes characterized by ``Fractal geometry'', a term coined in the late seventies by a famous mathematician, Benoit Mandelbrot.

The characteristic property of a fractal object is self-similarity or scaling, for example a branch of a tree resembles an entire tree, a little rock resembles a large mountain. Self-similarity is described mathematically by a power law decay of the distribution of object sizes. Scaling laws are often universal: they depend only on the main features of the system, such as the dimensionality of space, but do not depend on the details of interaction between agents.

In this course, we will study several examples, which illustrate the behavior of complex systems. This will include excursions into such hot topics as **economics, ecology, bio-informatics, biochemistry**, and, of course, **physics** (which may seem not so hot these days but serves as a foundation for all the rest).

The ideas of scaling and universality will be our unifying theme.

The research in complex systems is two-fold: first we must analyze the data from real systems. We will find plenty of these data on the Internet. And second, we must build mathematical models to understand the behavior of real systems.

In both steps we will extensively use computers. Homework assignment will include problem solving by writing simple computer programs. I will provide a brief introduction into C programming language using concrete examples from our course. However, the students will be encouraged to use any other computational tools, they are familiar with.

Pre-requirements for this course are basic calculus and basic calculus-based physics.

A list of possible topics:

- Simple systems leading to Gaussian and Poisson distributions.
- Percolation: an example of critical behavior; a model of forest fires.
- Branching Processes: a model of genetic survival.
- Invasion Percolation : an example of self-organized criticality.
- Bak-Sneppen model of evolution.
- Fractal dimension of polymers in solvent; self-avoiding walks.
- Levy flights and walks: a model for biological foraging.
- Diffusion-Limited Aggregation: a model for a bacteria colony.
- Logistic Equation: an example of chaotic behavior. A model for population
- dynamics.
- Statistical properties of DNA: an example from bioinformatics.
- Stock-market fluctuations and industrial firm growth.
- Complex networks: models of social interactions and the Internet.

Bibliography:

1. N. Boccara, Modeling Complex Systems, (NY, Springer, 2004).

2. D. Stauffer and A. Aharony, Introduction to Percolation Theory, 2nd ed. (Taylor and Francis, London,1994)

3. A. L. Barabasi, Linked, (Perseus Publishing, Cambridge MA, 2002).

4. P. Bak: How Nature Works, (NY, Springer, 1996)

5 P. G. De Gennes, Scaling Concepts in Polymer Physics (Ithaca, Cornell Univ. Press, 1979)

7. B. B. Mandelbrot, Fractal Geometry of Nature, (SF, Freeman, 1977)

8. D. Stauffer and H. E. Stanley, From Newton to Mandelbrot, (Berlin, Springer, 1996)

9. R. Mantegna and H. E. Stanley, An Introduction to Econophysics (Cambridge, Cambridge University Press, 1999).

For more information contact Dr. Buldyrev at buldyrev@BU.EDU